University of Baghdad *College of Engineering* *Petroleum Department*
Third Stage *Drilling Engineering I*
2024-2025 *Prof. Dr. Faleh Almahdawi*

Drilling fluids

Nature and composition of drilling fluids:

An ideal drilling fluid consists of the followings:

1- The continuous phase which is the base liquid like water, salt water, or oil.
2- Dispersed phase which are the solid particles mud cake like bentonite.
3- Inert solids like barite which is used to weighten the mud, and the drilled solids.
4- Additives which include the chemicals and thinners used to control mud properties. (NaoH, Cl, FCLS, KOH, CMC, starch, gilsonite …)

Types of clay used for drilling mud preparation

1) Bentonite group:

This group contains montmorillonite as its main mineral. $0.33Na\ (Al_{1.67}\ Mg_{0.33}\ O_3).\ 4SiO_2.H_2O$

Montmorillonite is composed of plains bonded with the sodium ion, when water is added the mineral disperses and swells water changing to a colloidal structure bentonite has a very large surface area which allows high dispersion and good colloidal properties.

2) Attapulgite group:

It is a fibrous mineral which do not disperse easily. It is very suitable to prepare drilling muds from salt water (like sea water). It has high filtration rates.

Yield of clay (Y):

It is a quick method to evaluate the clay ability to produce good drilling mud. **“It is the number of drilling mud barrels which has 15 cp viscosity which can be obtained from 1 ton of dry clay when mixed with water”. Yield of clay depend on:-**

1- Purity of clay

2- Nature of the atoms present in exchangeable layer

3- Salinity of the water used

$$\mathbf{Y = \frac{572}{X} - 3.4}$$

Y: Yield bbl mud/ton clay

X: Weight % of bentonite in mud

By this equation we can classify clays to:

1- Weak clay y<19 bbl
2- Normal clay y = 19-65 bbl
3- Good clay or metabentonite y = 65-88 bbl
4- Bentonite clay y>88 bbl

Properties of clay in water

1) Ionization and Hydration of Clay Particles

Mixing of clay and water can absorb a large amount of water into the water surface of individual of clay (Hydration). Hydration leads to the transformation of clay from dry powder to plastic slurry with an increase in volume of several hundred percent (swelling), which provide the clays their desirable high viscosity and yield point.

Degree of swelling and dispersion of clay will depend on nature of cations (positive Ion) on the outer surface of clay plates. The most common cations are:

Li, Na, Mg, Ca, Sr, Ba, H

High dispersion Low dispersion

2) Cation Exchange

A process of replacement the original cations in suspension the clay and water by another type of cation. This process leads to change the properties of the original clay such as hydration, diversion, viscosity, and filtration.

According to cation activity from weak to strong, the arrangement of cations will be:

Weak (H, Ba, Sr, Ca, Mg, Na, Li) strong

Cation exchange property can be used to prepare lime drilling mud and reduced the viscosity of bentonite and water suspension as follows:

$2Na\ Bent + Ca^{+2} \longrightarrow Ca(Bent)_2 + 2Na^{+}$

Good properties Poor properties

Ex.: From poor suspension to good suspension

$Ca\ (Bent)_2 + 2Na^{+} \longrightarrow 2\ Bent\ Na + Ca^{+2}$

Cation Exchange Capacity (CEC):

The quantity of cations available for exchange (mill eq/100gm clay)

The compound	CEC MEQ /100 gm
Montmorillonite	60 - 150
Illite	10 – 40
Chlorite	10 – 40
Kaolinite	3 - 15

3) States of clay suspensions

When a suspension of clay and water is agitated there are three model of plate association which is:

1- Edge to edge
2- Face to edge
3- Face to face

Depending on the type of clay plate association four different states can be distinguished which are:

1) Dispersion

When the individual clay plates are suspended in solution with no face or edge association between these plates.

2) Aggregation

Where there is face to face association of clay plates which results in decrease in viscosity and gel strength. Addition of cation (Ca^{+2}) may achieved this effect **lime** and **gypsum**.

3) Flocculation

Occurs when clay plates associated together through the edges and faces, which resulted in formation of flacks of clay particles and excessive gelation, there are two types of flocculation which are:

A) Electrolytic Flocculation

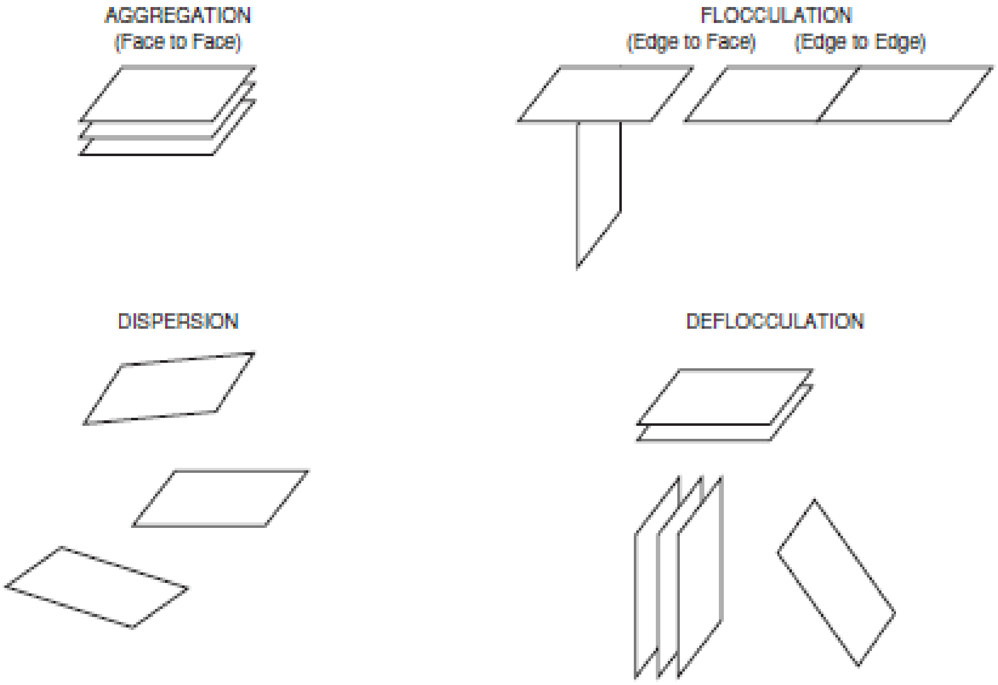
Caused by salts (NaCl, $CaSo_4.2H_2O$) which lead to deposition of clay flacks and decreasing viscosity, increasing of filtration.

B) Thermal Flocculation

Caused by high temperature.

4) deflocculation

Caused by chemicals (thinners) which broken up the edge to face plates association. See figure below

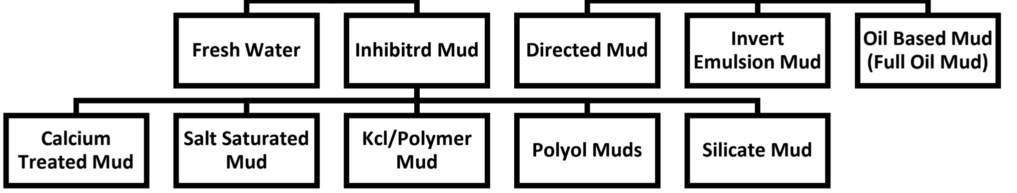


Association of clay particles

Types of Drilling Fluid

The two most common types of drilling fluid used are **water based mud** and **oil based mud**. **Water-based muds (WBM)** are those drilling fluids in which the continuous phase of the system is water (salt water or fresh water) and **Oil based muds (OBM)** are those in which the continuous phase is oil. WBM's are the most commonly used muds world-wide. However, drilling fluids may be broadly classified as liquids or gases (see figure below). Although pure gas or gas-liquid mixtures are used they are not as common as the liquid based systems. The use of air as a drilling fluid is limited to areas where formations are competent and impermeable. The advantages of drilling with air in the circulating system are: **higher penetration rates; better hole cleaning; and less formation damage.**

However, there are also two important disadvantages: air cannot support the sides of the borehole and air cannot exert enough pressure to prevent formation fluids entering the borehole. Gas-liquid mixtures (**foam**) are most often used where the formation pressures are so low that massive losses occur when even water is used as the drilling fluid. This can occur in mature fields where depletion of reservoir fluids has resulted in low pore pressure.



Types of Drilling Fluid

1- Water-base mud

A- Fresh Water Mud

It consists of four basic phases;

- Fresh water
- Active colloidal solids
- Inert solids
- Chemicals

Water is the continuous phase of any water-based mud. Primary function of the continuous phase is to provide the initial viscosity which can be modified to obtain any desirable rheological properties. The second function of the continuous phase is to suspend the reactive colloidal solids, such as bentonite, inert solids, such as barite. In water based mud's, clay is added to increase density, viscosity, gel strength and yield point, and to decrease fluid loss.

Advantages:

1- Low cost
2- Good penetration rates
3- Good solids removal
4- Excellent conditions for geoscientific investigations

Disadvantages:

1- Cannot used for drilling shale or clay formation, since the clay increase viscosity, gel strength and decrease filtration.
2- Low resistance to salt contamination such as NaCl, $CaSo_4$, $CaSo_4.2H_2O$, $Ca(OH)_2$, for high concentration of salts (flocculation), calcium mud, salt mud, and oil based mud could be used for drilling these formations.
3- Low thermal stability at high depths.
4- Poor cuttings transport efficiency
5- No static carrying capacity
6- Poor lubricity coefficient
7- Uncontrolled filtration
8- Poor borehole wall support

B- Inhibited Muds:

Is mud in which the ability of active clays to hydrate has been reduced greatly. These can be classified in to:

1- Calcium treated muds

They are used for drilling clay, shale and massive sections of gypsum and hydrite due to pressure of calcium cations in the mud which reduced the swelling and hydration of clay. It characterized by:

1. Low viscosity due to cation exchange from Na^{+2} to Ca^{+2} and for releasing some of adsorpe water from sodium bentonite.
2. High resistance to flocculating salts (50000 ppm for NaCl).
3. Low gel structure and filter loss.
4. Ability to tolerate high concentration of drilled solids without affecting the viscosity of mud.

Calcium muds can be classified according to source of Ca^{+2} ions and percentage of soluble calcium in the mud as follow:

A) Lime mud

Lime Mud which contains up to 120 ppm of soluble calcium and it is prepared by mixing bentonite, lime [Ca(OH)2], thinner, caustic soda and filtration control agent. Their pH(11.5-12.5) and thermal stability in range 100-120 ^oC.

For temperature > 120 ^{o} C, lime reacts with bentonite and from a rock of calcium silicate (solidification).

B) Gypsum mud ($CaSo_4.2H_2O$)

Gyp Mud which contains up to 1200 ppm of soluble calcium. It is similar to lime mud except that the lime is replaced by gypsum and they have higher temperature stability. pH (9.5-10.5).

C) Lignosulphonate Mud

This mud type is considered to be suitable when:

- High mud densities are required,
- Working under moderately high temperatures
- High tolerance for contamination by drilled solids
- Low filter loss is required.

This type of mud consists of fresh water or salt water, bentonite, ferrochrome lignosulphonate, caustic soda, CMC or stabilized starch. It is not suitable for drilling shale sections due to adsorption of water.

2- Salt saturated mud

The water phase is saturated with (NaCl) with concentration reach to 315000 ppm (offshore drilling). It used for drilling salts domes. Salt sections due to its ability to prevent hole enlargement. Also, when polymer is added to salt mud. It can be used to inhibiting swelling of shale and clay formation.

A salt water mud consist of:

1) Fresh, brine, or sea water
2) NaCl
3) Polymer
4) CMC, antifoaming agent
5) Zeogel (A clay used for preparing salt muds instead of bentonite)
6) Anticorrosion
7) NaOH

To convert water based mud into inhibitive mud using the following additives:

1) Adding calcium
2) Adding filtration loss
3) Adding thinners
4) Adding NaOH

****Salt muds (NaCl)**: This type of mud consists of salt concentration less than salt saturated mud.

3- Low solid-Non dispersed muds (KCl / Polymer Mud)

The basic components of KCl/polymer mud’s are:

- Fresh water or sea water
- KCl
- Inhibiting polymer
- Viscosity building polymer
- Stabilized starch or CMC
- Caustic soda

- Lubricants

This mud is suitable for drilling **shale sections** due to its superior sloughing inhibition properties. It is also suitable for drilling potentially productive sands.

The advantages of this type of mud are:

- Higher shear thinning
- High true yield strength
- Improved bore hole stability
- Good bit hydraulics and reduced circulating pressure losses.

The disadvantage is their instability at temperatures above 250 ^oF.

2- Oil Based Muds

Oil based mud’s has been defined as a system the continuous or external phase of which is any suitable oil. At the present time, there are two mud systems the external phase of which is oil

1) True oil mud’s (Full oil mud)
2) Invert emulsion mud’s.

1) True oil mud’s (Full oil mud)

True oil mud systems consist of the following components:

- Suitable oil
- Asphalt
- Water (water content <5%)
- Emulsifiers
- Surfactants
- Calcium hydroxide
- Weighting materials
- Other chemical additives

Among all of these, only oil and asphalt are necessary for the proper functioning of oil mud’s. The others are only used for the purpose of enhancing and stabilizing rheological properties and plastering characteristics. Different types of oils have been used as the continuous phase in oil mud’s. The following commonly available oils have gained widespread acceptance;

- Lease crude oil

- Refined oils

The following specifications are used as guidelines for the selection of oil:
Specific weight (API gravity): For viscosity purposes
Aniline point: A measure for the aromatic content of the oil
Flash point: It is the temperature at which oil vapor ignites upon passing flame over the hot oil
Fire point: It is the temperature at which continuous fire is sustained over the oil surface when flame is passed over it
Although presence of water is not required in oil mud's, some water is generally added to react with chemical additives in order to enhance the rheological properties and plastering characteristics of oil. A number of bodying agents have been used in oil mud's to achieve the desired rheological and filtration loss characteristics. Bodying agents can be classified into two groups:

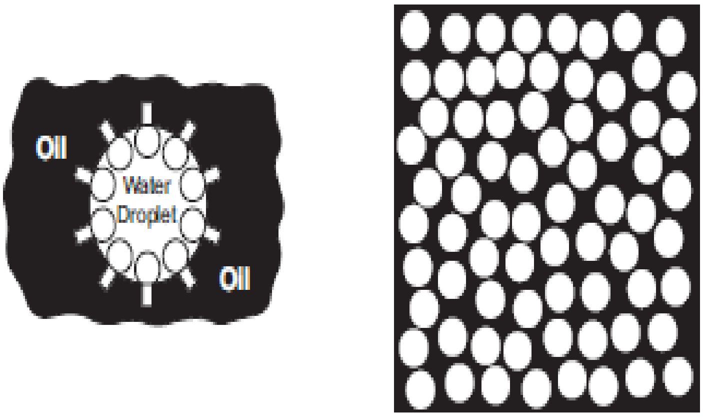
- Colloidal size materials
- High molecular weight metal soaps

Asphalts which are colloidal-size organophilic materials are used in oil mud have to impart required properties and control fluid loss, mainly through their absorptive characteristics. Asphalt work with the same principle as clays in water-based mud's.
Heavy metal soaps of fatty acids (emulsifiers) are added to the oil mud's in order to emulsify the water in oil. The functions of emulsifiers in oil mud's are as follows:

- Imparting weak gel strength to oil mud's because gel strength is necessary for suspension of weighting materials,
- Emulsification of any water picked up during drilling operation,
- Controlling the tightness of any water emulsion resulting from water contamination, thus, controlling fluid loss

2- Water in oil emulsions (water content 5 - 50%)

The water in invert emulsion muds is dispersed as small droplets throughout the oil. Emulsifiers coat the droplets, preventing them from coalescing and making the mud unstable (i.e. larger water droplets will settle out and break down the emulsion). A calcium or magnesium fatty acid soap is often used as an emulsifier in an oil based mud. The long hydrocarbon chain of the soap molecule tends to be soluble in oil while the ionic portion tends to be soluble in water. When soap is added to a mixture of oil and water the molecule takes up the position shown in Figure below.



Water droplets dispersed in a continuous oil phase.

The use of oil in the drilling fluid does have several **disadvantages**:

- Higher initial cost
- More stringent pollution controls required
- Reduced effectiveness of some logging tools (resistivity logs)
- Detection of kicks more difficult due to gas solubility in base oil

However for some applications oil-based muds are very cost effective. These include:

- To drill and core pay zones
- To drill troublesome formations (e.g. shale, salt)
- To add lubricity in directional drilling (preventing stuck pipe)
- To reduce corrosion
- As a completion fluid (during perforating and workovers)

3- Aerated Muds

Interest in under balanced drilling is increasing worldwide. In under balanced drilling operations, pressure of the drilling fluid in the borehole is intentionally maintained below the formation pore fluid pressure, in the open hole section of the well. As a result formation fluids flow into the well when a permeable formation is penetrated during under balanced drilling. Usually, aerated fluids are used in under balanced drilling operations. Most frequently used aerated fluids are air-liquid mixtures, foams, mist and gas.

The hydration of clays is severely reduced if the water used to make up the mud contains a high salt concentration. If a shale zone is being drilled with a freshwater mud the clays in the formation will tend to expand and the wellbore becomes unstable (sloughing shale). **By using a mud containing salt or calcium there will be fewer tendencies for this problem to occur**. An inhibitive mud is defined as one where the ability of active clays to hydrate has been greatly reduced. **Another advantage is that the water normally used in hydration is available to carry more solids. Inhibitive muds are principally used to drill shale and clay formations**, and are characterized by:

- Low viscosity
- Low gel strength
- Greater solids tolerance
- Greater resistance to contaminants